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Perspectives and assessments of solar PV power engineering in the Republic of Serbia

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ABSTRACT

The purpose of this paper is to review some key issues and prospects related to solar photovoltaic (PV) power engineering in the Republic of Serbia. The solar PV energy sector in the Republic of Serbia is poorly developed, despite the very good geographical position of Serbia and recent introduction of feed-in-tariffs (FITs) by the Serbian Government. This paper is aimed at analysing and assessing the potential, status and perspectives of solar PV power engineering in the Republic of Serbia. Solar radiation maps for the territory of Serbia using PVGIS ©software are presented and discussed. Some practical data and considerations are given from the point of view of a customer or company keen to invest in the solar PV electricity production in Serbia. The importance of the research and educational support in the field of solar PV power engineering is emphasised. The aim of this paper is to encourage further analyses and eventually investment in the PV energy sector in Serbia. It is expected that the Serbian authorities will refine and improve their regulatory policy in the field of renewable energy sources (RES) particularly within solar PV power engineering sector. The results of this study show that the Republic of Serbia has great potential for utilizing stand-alone and grid-connected solar PV energy systems and can seriously rely on this important RES sector in the future.

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1. Introduction

1.1. RES and PVs

Alarming trends in global energy demand, the future depletion of fuel energy sources and an incoming era of deficiency in energy present challenges to the world community to adapt the current energy system into a more sustainable one. In light of the Kyoto Protocol commitment, increased usage of energy produced from renewable energy sources (RES) presents the best possible means to combat climate change. During the last decade countries and governments worldwide have built stringent energy policy frameworks to expand utilization and investments in the alternative and RES sector. In this field the European Union (EU) certainly has a leading position in world society. The EU is at present developing an energy policy whose target is the transformation of the entire energy system by using low-carbon and RES technologies through the European Strategic Energy Technology Plan (SET-Plan) [1].

Amongst other RES possibilities solar photovoltaic (PV) power plants and systems have become a reality [2,3]. PVs have gained worldwide acceptance for producing clean, soundless, heatless and almost completely environmentally friendly renewable energy in the form of direct electricity conversion from sunlight. Apart from the apparent success of the first and second generation of semiconductor PV technology, significant progress can be expected in the nano-science and nano-technology area of PV research, which will enable low-cost fabrication of high-efficient next-generation PV cells and systems.

According to reference [4], the shares in the newly installed electricity generation capacity in Europe during a single year 2009 are: wind RES capacities 10.2 GW, gas 6.6 GW, PVs 5.8 GW, coal 2.4 GW (but decommissioned 3.3 GW), biomass 0.6 GW, nuclear 0.4 GW (but decommissioned 1.3 GW), etc. This data shows the growth of the European (and also the world's) PV market, industry and implementation in grid-connected solar PV power plants. PVs are in third place in Europe at the moment, soaring to be the first in the race very soon. At the moment the average installation cost for PV produced electricity is between 3 and 4 €/W of PV installed power, while a cost of less than 1 €/W is required for Grid-parity for PVs. Some optimistic forecasts say that this could happen in the forthcoming two or three decades.

To achieve Grid-parity for PVs further intensive research support is required. In the EU the European Photovoltaic Industry Association (EPIA) in 2009 [5] established PV technology as a mainstream clean, sustainable and competitive energy technology with a plan to provide up to 12% of the European electricity demand by 2020, up to 20% in 2030 and 30% in 2050. Amongst the variety of current obstacles, only price reductions due to technology improvements and the high penetration of grid-connected PV power plants in electricity grids could substantially help in achieving the 12% goal and to win the race with the traditional energy sources and particularly with other RES.

1.2. Serbian RES policy

The Government of the Republic of Serbia has established a firm political consensus on joining the EU and introduced European integration as its main political target. Together with other legislation, the Serbian Government is rapidly changing and adopting the Serbian energy sector policy framework. The Energy Law (2004) [6], the Environmental Protection Law (2004) [7] and the Energy Sector Development Strategy of the Republic of Serbia until 2015 (2005) [8] have laid a pathway for the future Serbian energy sector to enable integration with the European energy sector and also for its modernization. The National Assembly of the Republic of Serbia is steadily improving its legislation in energy and RES sectors, for instance the most recent version of Feed-in tariffs Act was adopted in December 2009 [9].

The Republic of Serbia has ratified and signed a number of Acts and Laws, acquiring modern European initiatives and programs and implementing them in everyday industrial, economical, educational and other activities. In 2007 Serbia ratified the Kyoto Protocol [10] and the Serbian National Parliament is obliged to meet the requirements of a dozen EU official Acts concerning the energy sector. Some of the most important are: Directive 2001/77/EC from 2001, Directive 2003/30/EC from 2003 and Directive 2009/28/EC from 23rd April 2009 (went into force in June 2009) on the promotion of the use of energy from renewable sources with a declared mandatory EU target aimed at increasing the RES share in the total EU energy consumption to at least 20% by the year 2020. The Republic of Serbia is a founder member of the International Renewable Energy Agency (IRENA) established in 2009 [11,12].

Therefore, it is obvious that the Government of the Republic of Serbia has taken some crucial steps in preparing policy framework for RES implementations in practice. However, this is not enough, because there are a lot of other obstacles (for example administrative) which have to be removed to allow Serbia the successful implementation of its RES legislation and RES, particularly PV, utilization in practice.

1.3. FITs in Serbia

The recent introduction of feed-in-tariffs (FITs) in Serbia is perhaps the most significant indicator of Government determination to follow the modern European energy policy standards and trends in the RES sector. FITs are certainly the most effective way to stimulate and to promote the growth of the renewable energy capacity. FIT can be defined as a mandatory rate (in € cents (c€) per kWh in Europe) at which the electricity retailers are obliged to purchase the electricity produced from RES. FITs have particular importance in the development and promotion of solar PV grid-connected systems because PVs are the most expensive of all new renewable technologies being developed today. Two decades ago (in 1991) Germany was the first European country to officially introduce FITs. Following Germany's lead, many European countries have adopted FIT support for PV produced electricity in combination with flexible policies that enable additional support with cheap bank loans and public grid access, tax benefits of different magnitudes and other incentives and measures to obtain a situation where PV has become a profitable investment option.

In 2008 the Serbian Government's energy sector experts group proposed FIT at 35.4 c€/kWh for electricity produced from solar PV grid-connected power-plants [13]. However, FIT at 23 c€/kWh has been recently adopted [9] applying from 1st January 2010. Unfortunately, a proposed FIT-unit incentive has been reduced by about 35%, and FITs are only guaranteed for 12 years for all RES power plants, including solar PV power-plants. A low level of adopted FITs for PVs, the short-term security period and lengthy administrative procedures for PV operation permissions are probably the main reasons why the development of PV power-plants in Serbia is still at the very beginning. It is obvious that the Serbian Government has to improve FIT incentives and overall RES policy and to provide additional tax-relief, subsidy programs and other incentive support if success in practice is the real target of the Government.

1.4. RES energy sector in Serbia

So far, utilization of RES in Serbia is limited to micro and mini hydro-power-plants. As it was stated in reference [14], Serbia has large unused potential for production of energy from RES (significant biomass and biogas resources [15], geothermal energy potential [16], wind energy potential, non-utilized hydro-

power potential, solar energy resources). In the Republic of Serbia, electricity is almost completely generated in traditional large power-plants, about 28% by using hydro-power and about 72% by using fossil fuel (mainly coal) [17]. The share of RES (micro and mini hydro-power-plants) is negligible – less than 1%. Unfortunately, in spite of the large natural potential of RES and the Serbian Government rhetoric promotion of the production of electricity from RES as a top priority, wind energy, solar energy and biomass energy are still not used for electricity generation in Serbia, nor is any geothermal source (the territory of Serbia is rich in geothermal wells) used for the production of heat energy.

The territory of Serbia is irradiated by the Sun more than, for example, Germany (Northern Europe) or the Czech Republic (Central Europe) – both of these countries being leaders in PV power engineering in the EU. The territory of Serbia has a significantly higher number of sunny days than many other European countries (over 2000 h annually). Unfortunately, the example of Serbia shows that the high level of Sun irradiation and large number of sunny days is not decidedly important for the level of development of solar PV power engineering. Not one solar PV grid-connected power plant operates in Serbia as yet. There are just some rare examples of individual solar thermal building systems and small solar PV roof maintained units, all of them operating in stand-alone regime. Examples and experiences from neighbouring countries (such as FYR Macedonia, Bulgaria, Greece, etc.) could help Serbia to achieve a more efficient RES policy and appropriate action plan for successful RES utilization.

1.5. The article content

The content of this article is as follows: in Section 1 the active policy of the Serbian authorities in the RES energy sector is briefly explained and the introduction of the FIT incentive is highlighted. In the next section, maps of average solar irradiation for the territory of Serbia arranged by using PVGIS © on-line interactive calculator [18] are presented and discussed. Some practical data for solar irradiation and estimated power production by a PV system with normalized installed power for several representative cities in Serbia is calculated and analysed. A brief reminder of the most important properties and parameters of solar PV cells and systems is given in the next section, together with an example of a feasibility study on a solar PV grid-connected system in the Republic of Serbia. Some important conclusions are drawn on the basis of this analysis and these conclusions can offer appropriate guidance on the present situation and on future investments in solar PV power engineering in Serbia. Some descriptive examples from the neighbouring countries' experiences in PV systems implementation are recalled as well. Further, the importance of educational and information dissemination in the RES sector and particularly with PVs in Serbia is emphasised. Through the paper a lot of suggestions are made, not only for professionals interested in the RES sector, but some of them can also be addressed directly to the Serbian Government with great will and expectation that the Government is going to improve its attitude and regulatory policy towards development and investment in solar PV power engineering in Serbia.

2. PVGIS maps and data of solar irradiation in Serbia

In this section data for annual solar irradiation and potential power production by PV power installations for the territory of the Republic of Serbia is calculated by using the PVGIS interactive on-line calculator (http://re.jrc.ec.europa.eu/pvgis/apps/, or http://sunbird.jrc.it/pvgis/apps/) [18].

2.1. PVGIS

PVGIS (*Photovoltaic Geographical Information System* – PVGIS ©European Communities, 2001–2008) is a part of the SOLAREC action aimed at contributing to the implementation of renewable energy in the EU. SOLAREC is an internally funded project on PV solar energy for the 7th Framework Programme. PVGIS has been developed at the JRC (Joint Research Centre) of the European Commission within its Renewable Energies Unit since 2001 as a research GIS oriented tool for the performance assessment of solar PV systems in European geographical regions. At the very beginning PVGIS was planned to be an in-house decision support system, fortunately access to the PVGIS database and estimations has been made freely available to professionals and the general European public through web-based interactive applications. PVGIS is aimed at providing data to analyse the technical, environmental and socio-economic factors of solar PV electricity generation in Europe and to support systems for policy-making in EU countries. More about PVGIS and the data sources and methodology used can be found on the official web-site (http://re.jrc.ec.europa.eu/pvgis/) and references [19–22].

There are various databases and PV estimation tools offering solar radiation and other climatic data useful for an assessment of the PV potential for specific location worldwide: European Solar Radiation Atlas (ESPA), SoDa, NASA SSE, Meteonorm, etc. PVGIS as a solar radiation database has advantages over other similar databases as an open data and software PV estimation tool with an excellent geographical grid resolution (1 km × 1 km) and map based user-friendly interface, providing easy-understandable information for PV geographical assessments. The estimated accuracy of PVGIS calculations is proven to be within several percents [20]. Detailed geographical, climatic and other data make PVGIS on-line calculator ideally suited, not only for non-professionals and initial PV system estimations, but also even for serious PV systems design as part of the integrated management of distributed energy generation, for specifically selected locations in Europe.

PVGIS methodology takes into account not only solar radiation data, it considers PV module surface inclination and orientation and shadowing effect of the local terrain features (e.g. when the direct irradiation component is shadowed by the mountains), therefore PVGIS is a powerful PV implementation assessment tool that takes into account the dynamic nature of interactions between solar radiation, climate, atmosphere, the earth's surface and the PV technology used. Several fast web applications (written in C language) enable an easy estimation of the PV electricity generation potential for selected specific locations in Europe.

PVGIS interactive on-line calculator is used to calculate the yearly total of solar irradiation and PV power estimation for the territory of Serbia for PV modules placed in horizontal (e.g. roofs), vertical (e.g. south-facing buildings facades) and optimally inclined planes (for maximizing solar energy harvesting in grid-connected PV power plants).

A typical PVGIS value for the performance ratio (PV system losses) of PV systems with modules from mono- or polycrystalline silicon is taken to be 0.75 [18,19].

It is worth mentioning the fact that the results obtained from the PVGIS database and on-line calculator can differ from those provided by other providers of solar PV data. For detailed and much more trusted data one has to compare PVGIS calculations with data offered by other similar services [23]. The figures and tables presented in this article can serve as guidelines for the necessary data for solar radiation and design of PV grid-connected systems in the Republic of Serbia. It is obvious that every serious investor in PV power engineering in Serbia would take into consideration data from several databases from different specialized companies.

In this article the version PVGIS-3 is used. The PVGIS-3 dataset is based on measurements made on the ground in the period

Fig. 1. The geographical position of the Republic of Serbia in the South-East of Europe. The latitude range of the territory of Serbia is: from the farthest point South 41°47′40″ S up to the farthest point North 46°10′59″ N. The longitude range is: from the farthest point West 18°48′41″ W up to the farthest point East 23°1′59″ E.
Adapted for Serbia from PVGIS ©European Communities, 2001–2008 [18], http://re.ec.europa.eu/pvgis/.

1981–1990 which are then interpolated between points to get radiation values at any point. A new version PVGIS–CMSAF has been recently introduced which uses the new databases for the solar radiation data provided by the Climate Monitoring Satellite Application Facility (CMSAF) from the period 1998–2010 [18]. According to the possible wrong terrestrial measurements and to the fact that the amount of solar radiation has increased over Europe in the last 30 years, calculations with new PVGIS–CMSAF give higher values than with the older PVGIS-3. For the territory of Serbia PVGIS–CMSAF gives up to 5% higher values for the solar irradiation data.

2.2. PVGIS solar maps for the territory of Serbia

Fig. 1 shows the geographical position of the Republic of Serbia in Europe. Geographically, Serbia belongs to the South-Eastern European region spreading mostly on the Balkan Peninsula. It is a country with a diverse landscape with fields, forested hills and high mountains and a mainly continental climate with warm sunny rainless summers. Politically, the Republic of Serbia has been an independent republic since 2006. From 1991 to 2006 Serbia was in union with Montenegro (the independent Republic of Serbia and Montenegro) and before 1991 Serbia was one of the six Yugoslav republics, today all of them being independent states: Slovenia, Croatia, Bosnia and Herzegovina, Montenegro and FYR Macedonia. The Serbian autonomous province Kosovo and Metohija is under the United Nation Mission in Kosovo (UNMIK) administration (UNSC Resolution 1244 from 1999).

Fig. 2 shows data for average yearly values of total global irradiation in optimally inclined planes in kWh/m^2 for the territory of Serbia. It can be seen that yearly sum of global irradiation varies from 1380 kWh/m^2 in the north up to 1720 kWh/m^2 in the south. PVGIS obtained data shows that average irradiation is not dependent on geographical latitude only. There are regional differences in global irradiation for Serbia due to terrain features and local climatic conditions. A brief explanation of the methodology used and the influence of related climatic and terrain data can be found in references [21,22].

Serbia can be divided in the three main regions in respect to the level of the yearly sum of "optimal" total solar irradiation ("optimal" means that data is given only for PV modules situated in the south-facing optimally inclined planes):

- Northern and easternmost regions (about 25% of Serbia) where the "optimal" total solar irradiation does not exceed 1500 kWh/m^2,
- Central region (about 60% of Serbia) where the "optimal" total solar irradiation has values within a range of 1500–1600 kWh/m^2,
- South-eastern region (about 15% of Serbia) where the "optimal" total solar irradiation exceeds 1600 kWh/m^2.

In reference [20] five climatic regions within Europe have been identified: 1. Regions with the highest potential for solar electricity

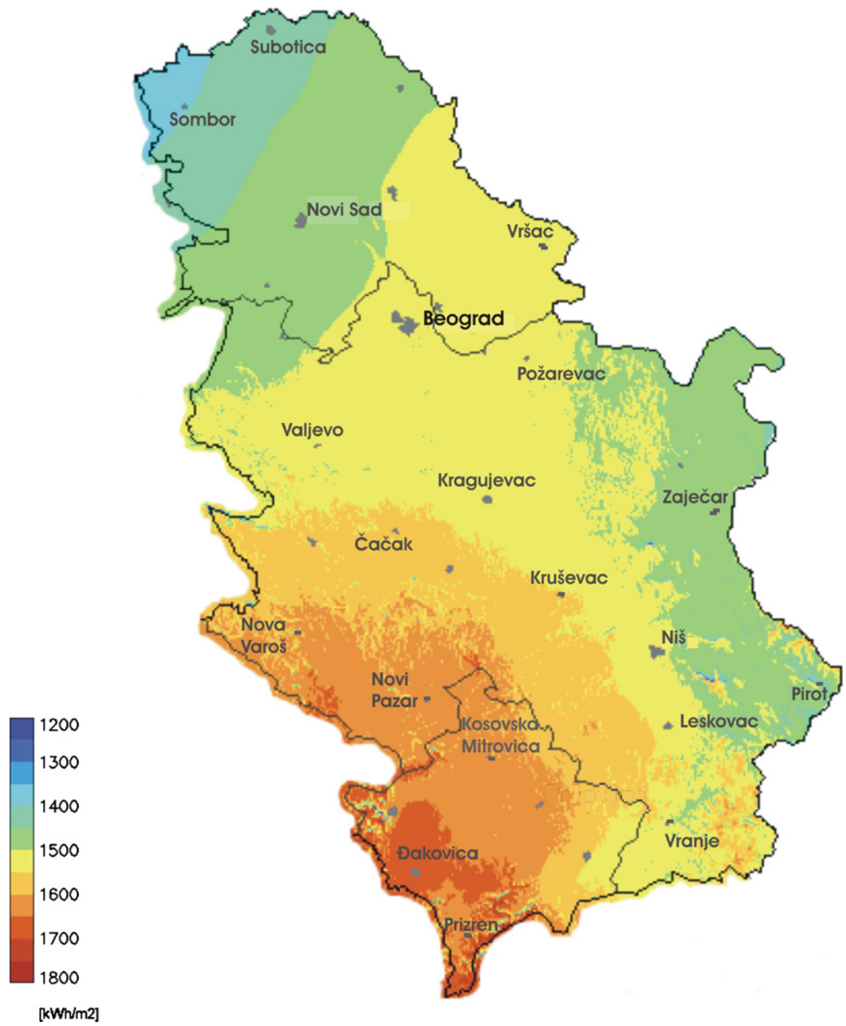

Fig. 2. Yearly sum of total solar irradiation incident on optimally inclined south-oriented PV modules in kWh/m^2 for the territory of Serbia. Adapted for Serbia from PVGIS ©European Communities, 2001–2008 [18], http://re.ec.europa.eu/pvgis/.

generation (e.g. Portugal, most parts of Spain, Italy, Croatia, Greece and Turkey); 2. Regions with favourable climatic conditions (e.g. Northern parts of Spain, Italy, in FYR Macedonia, and the Black Sea region); 3. Regions with good climate conditions such as France, Central European states; 4. Regions with less favourable conditions (e.g. Northwest Europe and Baltic states) and 5. The poorest regions for solar PV electricity generation (e.g. Scotland, North Sweden and Finland). According to this regional division, Serbia is a mixture of the 2nd and 3rd climate areas, having some territorial units with favourable climatic conditions but mainly good conditions for solar PV electricity production. Due to its continental climate (very hot and often rainless summers, but windy and snowy winters), the seasonal variation of PV electricity yields is significant for the territory of Serbia, with November, December and January being the worst and July and August the best months for PV electricity harvesting (about 3 times better sunny conditions during summer months). Significant daily variations in solar radiation and seasonal horizon-heights of the sun's position in the sky in Serbia suggest that the sun-tracking PV systems could be considered as the favourable solution in Serbia for PV investments in the future.

It is interesting to note that Fig. 2 gives different information for average values of total yearly irradiation data for the territory of Serbia than the figure presented in reference [14], where the map of the daily average of global solar energy on a horizontal plane for Serbia is given, or the figure presented on the official site of the Serbian Ministry of Mining and Energy (SMME) (http://www.mre.gov.rs/). Data sources which have been used for illustrations on solar irradiation data for Serbia in both of these references are not given, while the south-eastern part of Serbia is presented to be the most favourable region for PV utilization in Serbia. A discrepancy between them and the PVGIS obtained map in this article is noticeable. PVGIS data (Fig. 2) shows that the most favourable region for PV utilization is the south-western part of Serbia. The author of this article has explored the PVGIS methodology in detail and has checked PVGIS data against some other solar data services and his opinion is that PVGIS data might be favourable to those given in reference [14] and on the SMME official site. It is likely that solar irradiation data used for figures in reference [14] and SMME did not take into account some important factors such as local climate parameters, terrain features, etc.

Fig. 3 shows the map of optimum inclination angles (in degrees) of south-facing PV modules for the territory of Serbia ranging from 26° to 38° (prepared from the PVGIS ©European Communities database). It can be seen from Fig. 3 that the optimum inclination angle of south-facing PV modules for the territory of Serbia is mainly 33–35° (north, central and southern regions), a degree or two less for the eastern part and a degree or two greater for the western part of Serbia and with some additional fluctuations in respect to the regional (local) terrain features.

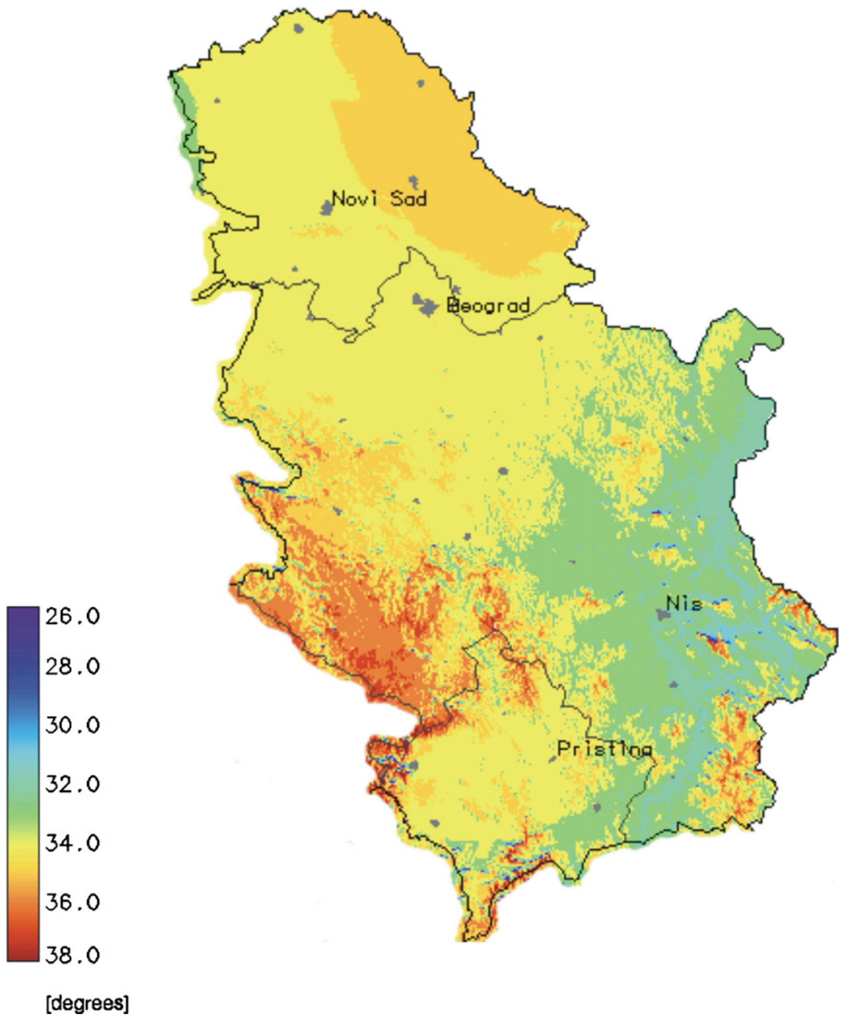

Fig. 3. Optimum inclination of South-facing PV modules for the territory of Serbia.
Adapted for Serbia from PVGIS ©European Communities, 2001–2008 [18], http://re.ec.europa.eu/pvgis/.

2.3. PVGIS solar data for Serbian cities

Table 1 shows data for the average annual irradiation for 20 representative cities in Serbia. The criteria used to choose those cities were: bigger regional Serbian cities with specific solar irradiation conditions. For each representative city the exact latitude and longitude data are given, as well as PVGIS calculated data for optimal inclination and orientation angles for PV module planes. Neighbouring cities to the representative one (cities with presumably, but not necessarily, similar irradiation conditions) are denoted in the next column. For each representative city average values of yearly total solar irradiation (in $Wh/m^2/day$) are given for three characteristic positions of PV modules: modules placed in a horizontal plane, in a vertical plane, and in a south-facing optimally inclined and oriented (azimuthally) plane. It is supposed that PV modules remain in a fixed (stationary) position every day for a year. The estimated power output from a PV system defined by the nominal installed power of 1 kWh and the performance ratio 0.75 to 0.76 (estimated PV system losses: 24–25%) is presented for a horizontal, vertical, optimally inclined and oriented module case, as well as for the two-axes sun-tracking PV systems. The last column in Table 1 gives the gain (in percent) which is obtained by using the sun-tracking instead of the fixed (but optimally positioned) PV system at the same location. The gain is calculated as the ratio: the sun-tracking PV system yields to fixed “optimal” PV system yields.

The PVGIS values of total yearly irradiation and PV yields data in the vertical plane in Table 1 are calculated for south-facing planes at a vertical inclination. The PVGIS values of yearly total irradiation in an optimally inclined plane (not necessarily exactly south-facing!) of the PV module are calculated for the angle of inclination that will receive the maximum amount of sunlight during a whole year. In general [20], solar PV modules mounted vertically (to the south) yield about 30% less electricity than modules placed horizontally (30–40% for the territory of Serbia), modules placed horizontally yield about 15% less electricity than solar PV modules placed in optimally inclined planes at the same location (12–15.5% for the territory of Serbia). The best results in solar energy harvesting can certainly be obtained by using the two-axis sun-tracking systems (for the territory of Serbia it gives about 30–35% more power yields than with fixed (stationary, non-tracking) PV modules placed in optimally inclined planes). On the other hand, the mounting and maintenance expenses for vertically mounted PV modules on the building facades are lowest (no land fees, without expensive additional mechanical equipment, etc.), while the design, mounting and maintenance expenses for the sun-tracking systems are the highest (unfortunately proportionally to the energy harvesting enhancement). The purpose for designing the PV system (building an integrated PV system or terrestrial PV system), the planned installed power (a few kW or several hundreds of kW), specific terrain features (including rural or urban conditions) and specific financial calculations

Table 1
Data for yearly averages of total solar irradiation and power output from a PV system with normalized nominal installed power of 1 kWh calculated for 20 representative cities in Serbia.

No.	Latitude (North) and longitude (East)	Representative Serbian city	Optimum angles of PV module planes for representative city		Accompanying cities and towns (neighbouring to the representative city)	Average yearly irradiation [in Wh/m^2/day]			Average yearly power output from a PV system with nominal installed power of 1 kWh [in kWh] and estimated PV system losses: 24–25%				
			Inclination	Orientation (azimuth)		In horizontal plane	In vertical plane	In optimally inclined plane	In horizontal plane	In vertical plane	In optimally inclined plane	With two-axes sun-tracking system	Gain (%): two-axes sun-tracking system/opt.incl.plane
1.	46°05′36″ N 19°40′05″ E	Subotica	35.0°	−1.0°	Horgoš, Palić, Senta	3428	2617	3908	954	730	1097	1428	30.2%
2.	45°46′09″ N 19°07′21″ E	Sombor	34.0°	−1.0°	Crvenka, Kula	3372	2536	3816	938	706	1070	1384	29.4%
3.	45°14′59″ N 19°49′59″ E	Novi Sad	34.0°	0.0°	B. Palanka, Ruma Zrenjanin	3549	2693	4034	984	747	1127	1492	32.4%
4.	45°06′59″ N 21°17′59″ E	Vršac	35.0°	0.0°	Bela Crkva, Kovin	3644	2784	4166	1010	772	1163	1557	33.4%
5.	44°44′05″ N 20°33′21″ E	Beograd	33.0°	2.0°	Zemun, Pančevo, Obrenovac	3616	2708	4104	1005	750	1147	1463	27.6%
6.	44°37′26″ N 21°11′28″ E	Požarevac	34.0°	0.0°	Smederevo, V. Plana, Svijalnac	3643	2744	4140	1009	760	1154	1545	33.9%
7.	44°16′14″ N 19°53′53″ E	Valjevo	34.0°	−1.0°	Loznica, Ljig, Aranđelovac	3649	2779	4167	1014	773	1167	1552	33.0%
8.	44°00′59″ N 20°54′59″ E	Kragujevac	34.0°	−1.0°	Lapovo, Topola, Ćupija, Paraćin	3708	2789	4214	1029	774	1177	1582	34.5%
10.	43°53′59″ N 22°16′59″ E	Zaječar	32.0°	−3.0°	Bor, Knjažavac, Negotin	3641	2643	4070	1006	729	1130	1521	34.6%
9.	43°53′22″ N 20°21′22″ E	Čačak	35.0°	−3.0°	G. Milanovac, Užice, Kraljevo	3752	2851	4286	1042	793	1200	1613	34.4%
11.	43°34′59″ N 21°19′59″ E	Kruševac	33.0°	−3.0°	Trstenik, Stalać, Aleksandrovac	3771	2794	4259	1043	773	1186	1607	35.5%
12.	43°27′59″ N 19°47′59″ E	Nova Varoš	36.0°	−3.0°	Prijepolje, Priboj	3792	2995	4406	1074	850	1258	1651	31.3%
13.	43°18′59″ N 21°53′59″ E	Niš	32.0°	−3.0°	Aleksinac, Blace, Prokuplje	3696	2685	4136	1023	741	1151	1546	34.3%
14.	43°08′59″ N 22°34′59″ E	Pirot	32.0°	−1.0°	Dimitrovgrad, B. Palanka	3598	2587	4001	998	715	1115	1470	32.9%
15.	43°08′30″ N 20°31′22″ E	Novi Pazar	35.0°	3.0°	Raška, Tutin, Sjenica	3894	2964	4457	1089	829	1255	1654	31.8%
16.	42°58′59″ N 21°56′59″ E	Leskovac	32.0°	−3.0°	Vlasotince, Lebane, C. Trava	3744	2715	4189	1038	751	1167	1544	32.3%
17.	42°53′02″ N 20°52′31″ E	Kosovska Mitrovica	34.0°	−3.0°	Priština, Vučitrn, Leposavić	3885	2912	4425	1083	811	1242	1641	32.2%
18.	42°33′21″ N 21°54′37″ E	Vranje	33.0°	−2.0°	Bujanovac, Gnjilane, Preševo	3676	2707	4140	1027	756	1165	1523	30.8%
19.	42°22′59″ N 20°24′59″ E	Đakovica	34.0°	0.0°	Dečani, Orahovac	4007	3007	4587	1114	835	1285	1712	33.3%
20.	42°12′48″ N 20°44′53″ E	Prizren	33.0°	4.0°	Dragaš, S. Reka	3961	2911	4500	1102	806	1259	1646	30.8%

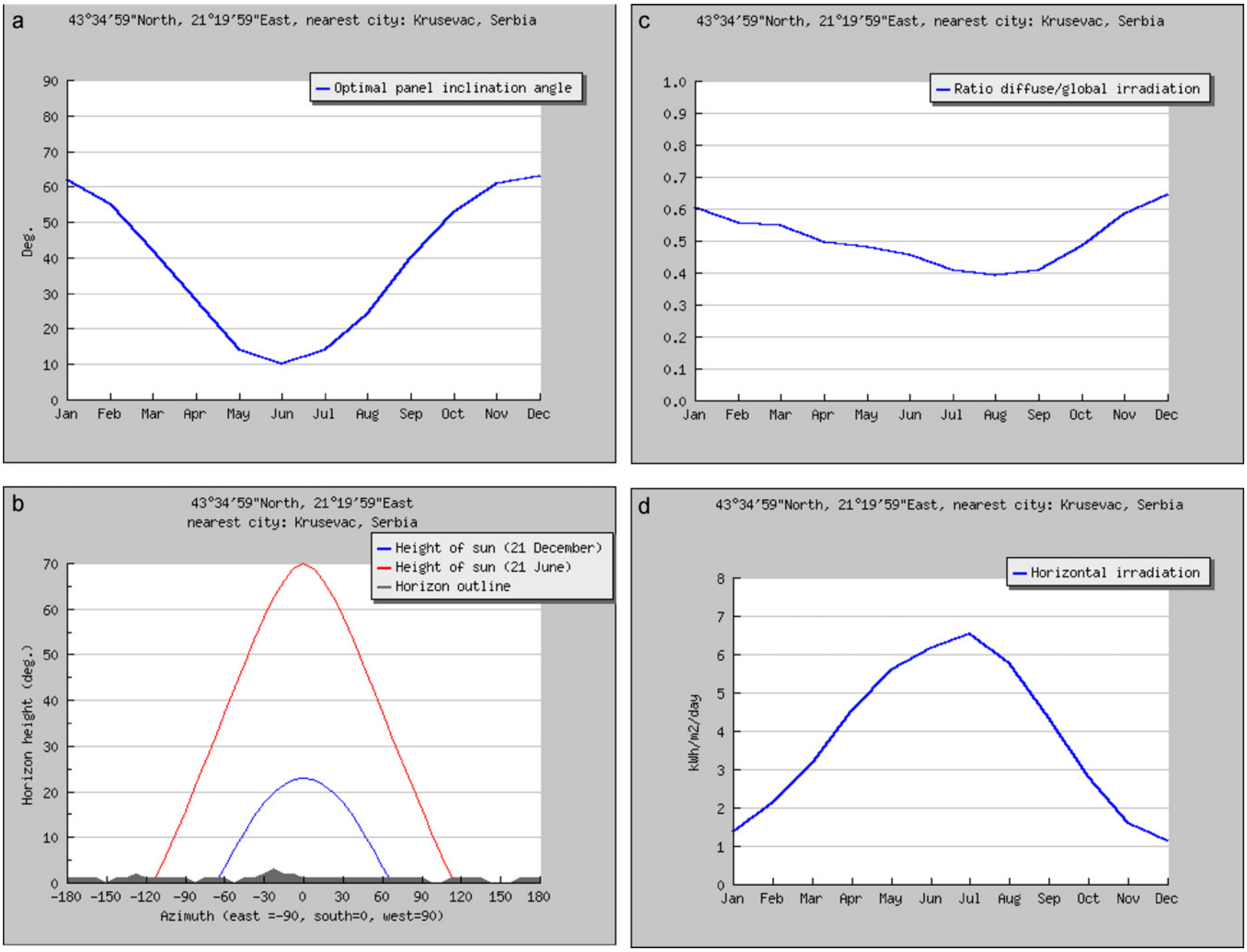

Fig. 4. (a) PVGIS calculation for estimated electricity production which can be expected each month (with a monthly average) from a PV system with nominal installed power of 1 kW, with stationary PV modules placed in an optimally inclined plane, placed in (or near to) the city of Kruševac, the central region of Serbia. (b) PVGIS calculation for estimated electricity production which can be expected each month (with a monthly average) from a PV system with nominal installed power of 1 kW, with a two-axis sun-tracking PV system, placed in (or near to) the city of Kruševac, the central region of Serbia. (c) PVGIS calculation for estimated electricity production which can be expected each month (with a monthly average) from a PV system with nominal installed power of 1 kW, with stationary PV modules placed in an optimally inclined plane, placed in (or near to) the city of Kruševac, the central region of Serbia. (d) PVGIS calculation for estimated electricity production which can be expected each month (with a monthly average) from a PV system with nominal installed power of 1 kW, with a two-axis sun-tracking PV system, placed in (or near to) the city of Kruševac, the central region of Serbia.

and costs will dictate the choice of the PV modules mounting position.

Fig. 4a–d shows some characteristic PVGIS diagrams for a PV system with nominal power of 1 kW, placed in the city of Kruševac, in the central Serbian region. The data illustrated in those figures represents mainly typical solar properties for Serbia by means of PV utilization. Table 1 shows some interesting PVGIS obtained data for the city of Kruševac which is situated in a very attractive position for sun-tracking PV system utilization (gain greater than 35%), probably due to the surrounding flat territory and specific microclimate.

Fig. 4a shows the variation of the optimal inclination angle over the course of a year. It can be seen that optimal inclination angle in June has the lowest value (about 10°) and in December and January reaches 60°, while the yearly optimum angle value is calculated to be 33° for fixed-mounted PV systems. Fig. 4b shows the horizon heights of the sun on 21st December and 21st June from sunrise to sunset. The ratio between the diffuse component and global or total irradiation (the sum of incident (beam), diffuse and reflected component) during a year is illustrated in Fig. 4c. The beam irradiation component dominates (between 50% and 60%) over the diffuse one in the sun-harvesting season (from April to October). The variation of the daily sum of irradiation for a horizontally placed PV module during the year in kWh/m^2/day is given in Fig. 4d. Although these data and figures are easily accessible on-line within the PVGIS applications, they are presented here as the typical solar data examples for PV assessments and analyses for Serbia.

Figs. 5a and b, 6a and b, 7a and b and 8a and b show PVGIS calculated values for estimated electricity production by a PV power system with nominal installed power of 1 kW, with PV modules placed in an optimally inclined plane for several cities in Serbia: Novi Sad (the northern region), Kragujevac (the central region), Leskovac (the south-eastern) and Novi Pazar (the south-western region). Data is calculated for a PV system assembled by mono- or polycrystalline silicon PV modules, with overall PV system estimated losses of 24–25%, placed firstly as fixed PV systems with optimal inclination (Figs. 5a, 6a, 7a and 8a) and then as two-axis sun-tracking systems (Figs. 5b, 6b, 7b and 8b) at the same locations. The monthly averages for estimated electricity production are denoted with a line as well. It can be seen from these figures that the sun energy harvesting is nearly 3.5 times greater in July than in December.

Table 2
The ratio of the total PV electricity production in the April to September summer period to the October–March winter period of the year for several Serbian cities. Additionally, the table gives an average daily production during December (the "worst" month for the PV electricity production), July (the "best" month for the PV electricity production), and yearly average per month for fixed optimally inclined and two-axis sun-tracking PV systems.

No.	Serbian city	Relative location in Serbia	PV production in period from April to September over PV production in period from October to March		Average values of PV electricity production per day [in kWh/day] for the "worst" month, the "best" month, and yearly average per month for fixed optimally inclined and two-axis sun-tracking PV systems					
			Fixed PV system, optimally inclined PV module plane	Two-axis sun-tracking PV system	December		June		Average monthly	
					Fixed	Sun-tracking	Fixed	Sun-tracking	Fixed	Sun-tracking
1.	Subotica	Farthest North	2.02	2.21	1.1	1.3	4.4	6.0	3.0	3.9
2.	Novi Sad	North	1.94	2.12	1.3	1.6	4.5	6.4	3.1	4.1
3.	Pirot	Farthest South-East	1.93	2.14	1.3	1.5	4.1	5.8	3.1	4.0
4.	Leskovac	South-East	1.89	2.09	1.3	1.6	4.6	6.5	3.2	4.2
5.	Kragujevac	Central	1.84	2.04	1.5	1.8	4.6	6.7	3.2	4.3
6.	Novi Pazar	South-West	1.66	1.85	1.7	2.1	4.7	6.9	3.4	4.5
7.	Đakovica	Farthest South-West	1.70	1.88	1.7	2.0	4.8	6.8	3.5	4.7

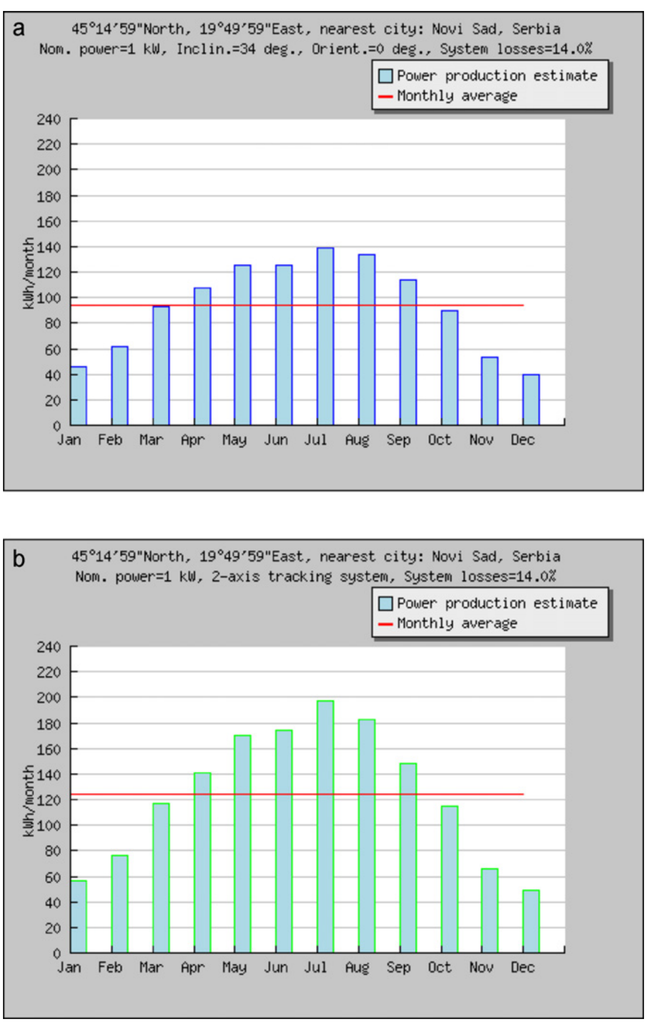

Fig. 5. (a) PVGIS calculation for estimated electricity production which can be expected each month (with a monthly average) from a PV system with nominal installed power of 1 kW, with stationary PV modules placed in an optimally inclined plane, placed in (or near to) the city of Novi Sad, the northern region of Serbia. (b) PVGIS calculation for estimated electricity production which can be expected each month (with a monthly average) from a PV system with nominal installed power of 1 kW, with a two-axis sun-tracking PV system, placed in (or near to) the city of Novi Sad, the northern region of Serbia.

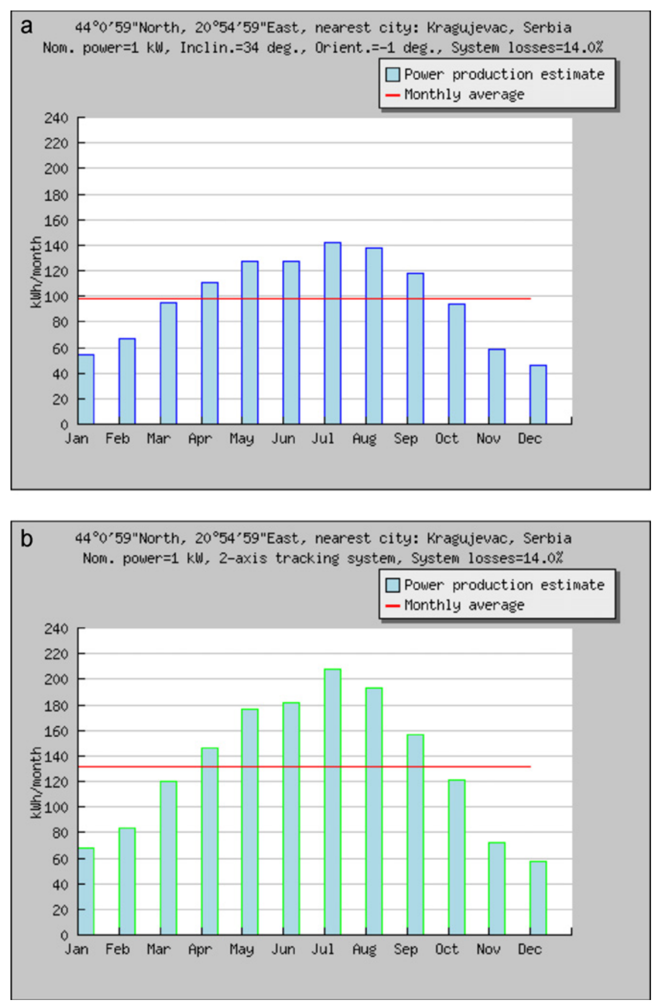

Fig. 6. (a) PVGIS calculation for estimated electricity production which can be expected each month (with a monthly average) from a PV system with nominal installed power of 1 kW, with stationary PV modules placed in an optimally inclined plane, placed in (or near to) the city of Kragujevac, the central region of Serbia. (b) PVGIS calculation for estimated electricity production which can be expected each month (with a monthly average) from a PV system with nominal installed power of 1 kW, with a two-axis sun-tracking PV system, placed in (or near to) the city of Kragujevac, the central region of Serbia.

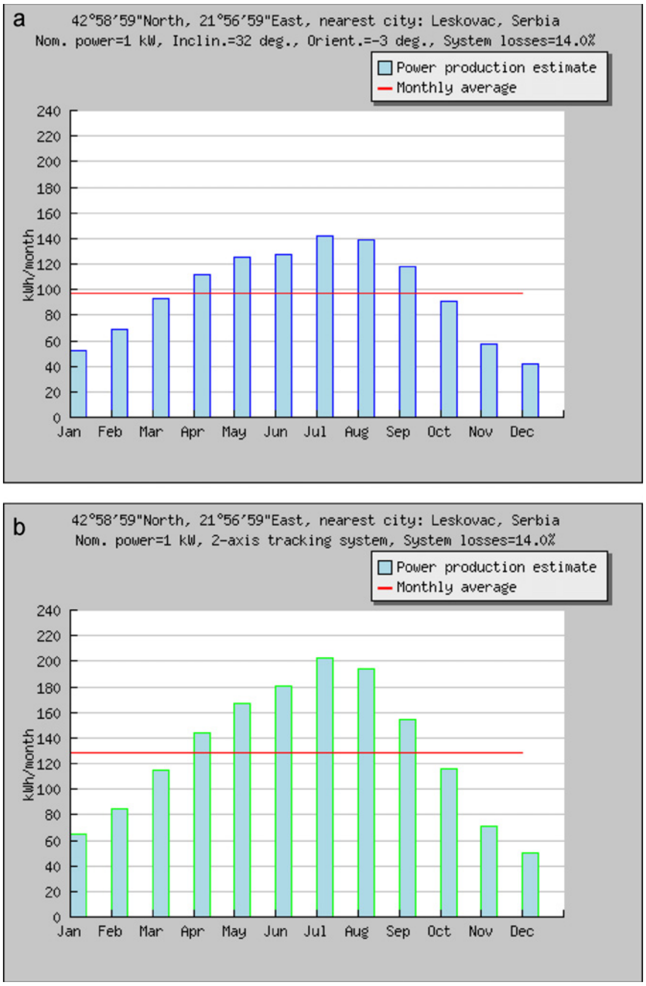

Fig. 7. (a) PVGIS calculation for estimated electricity production which can be expected each month (with a monthly average) from a PV system with nominal installed power of 1 kW, with stationary PV modules placed in an optimally inclined plane, placed in (or near to) the city of Leskovac, the south-eastern region of Serbia. (b) PVGIS calculation for estimated electricity production which can be expected each month (with a monthly average) from a PV system with nominal installed power of 1 kW, with a two-axis sun-tracking PV system, placed in (or near to) the city of Leskovac, the south-eastern region of Serbia.

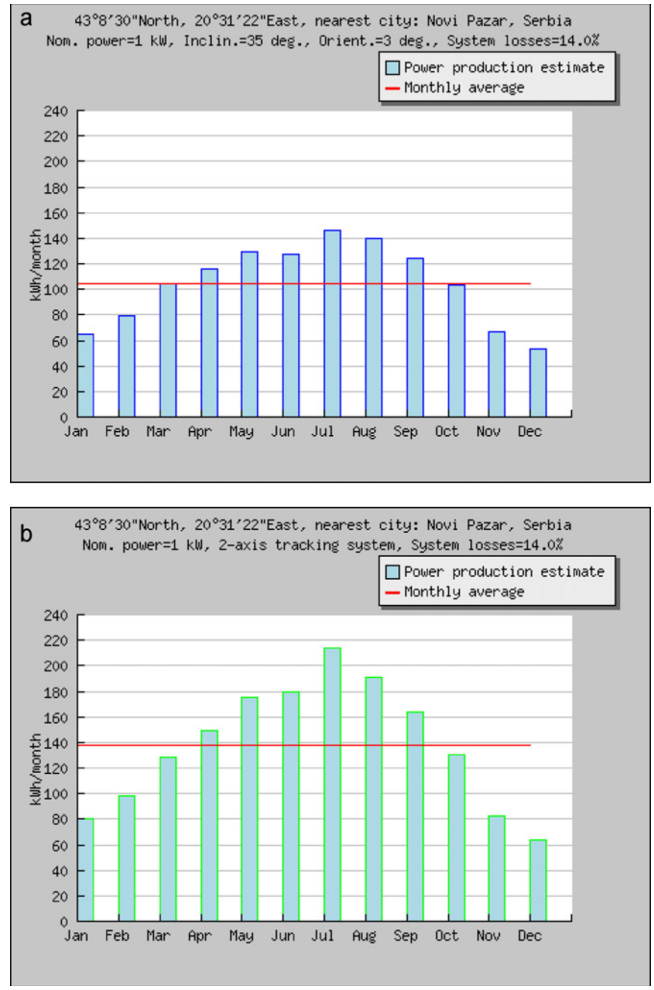

Fig. 8. (a) PVGIS calculation for estimated electricity production which can be expected each month (with a monthly average) from a PV system with nominal installed power of 1 kW, with stationary PV modules placed in an optimally inclined plane, placed in (or near to) the city of Novi Pazar, the south-western region of Serbia. (b) PVGIS calculation for estimated electricity production which can be expected each month (with a monthly average) from a PV system with nominal installed power of 1 kW, with a two-axis sun-tracking PV system, placed in (or near to) the city of Novi Pazar, the south-western region of Serbia.

A PV system would produce significantly more electricity during the summer season than during the winter season in Serbia. Table 2 gives calculated ratios of total PV electricity production in the April–September summer period to the October–March winter period of the year for several Serbian cities. Although the territory of Serbia is not huge, the differences are significant: on the farthest point north this ratio is about 2.0 for fixed and optimally inclined PV systems and 2.2 for two-axis sun-tracking PV systems, being lower for the farthest point South (about 1.7 for fixed PV systems and 1.85 for sun-tracking PV systems).

3. Guidelines for PV systems assessment and utilization in Serbia

Some basic definitions and terminology that is in general use in solar PV power engineering are given in the following subsection. This can be a helpful guide to a better understanding of the assessments presented in this section, particularly for PV beginners.

3.1. A brief PV reminder

The average power of the solar irradiance of 1 m^2 of the earth's surface is about 1000 W/m^2. Solar irradiance varies during the daytime, from season to season, from year to year, but it is mainly dependent on the geographic latitude. More precisely, a horizontal square metre of the Earth's surface receives, under Serbian geographic and climatic conditions, between 1200 kWh/m^2 in the north to 1500 kWh/m^2 in the south of solar irradiation annually (on average 1350 kWh/m^2), which gives a daily average of about 3.7 kWh/m^2. According to data published by PVGIS ©[19–21], in southern Europe annual solar irradiation can reach up to 1800 kWh/m^2 (over 1800 kWh/m^2 in some parts of Spain, Turkey, Cyprus, Portugal, Greece and Italy) and in northern Europe the irradiance drops to a low of about 700 kWh/m^2 (Sweden, Finland, Norway, United Kingdom and Ireland). It is well known that the direct (beam) solar irradiation is more than 50% and the remainder is the sum of mainly the diffuse and a small portion of reflected irradiation components.

The nominal peak power of the PV module or system is the declared power given by the manufacturer, and it is defined as the PV system power output under *Standard Test Conditions* (STC): at

$1000\,\mathrm{W/m^2}$ solar irradiance, a module temperature of 25 °C and a solar spectrum corresponding to an air mass of 1.5. A PV system with 1 kW of peak power is simply denoted as $1\,\mathrm{kW_p}$.

The energy harvested from the sun can be optimized by inclining planes of PV modules and panels to the angle when the conversion of solar energy to electricity is optimal as well as by positioning them in optimal east-west orientation (because of terrain shadowing effects the optimal orientation of PV modules may not be due south). Placing PV modules and panels in an optimally inclined plane and optimal east-west orientation, the annual solar irradiation and the energy harvesting can be improved about 15% (reaching $2000\,\mathrm{kWh/m^2}$ in southern Europe). It means that the average value of annual solar irradiation on optimally inclined and oriented PV module planes in Serbian conditions is between $1500\,\mathrm{kWh/m^2}$ and $1600\,\mathrm{kWh/m^2}$, with a daily average of about $4.3\,\mathrm{kWh/m^2}$. Further improvement in the harvesting of sunlight can be obtained by using sun-tracking PV systems. These systems allow PV modules to move and to follow (track) precisely the position of the sun in the sky. In this way, the amount of sunlight arriving at the PV modules can be increased by more than 30% (up to 50%) compared to optimally inclined and oriented (but whole year fixed) modules.

The conversion efficiency, the most important property of the solar cell, is the ratio of the PV generated electric output power to the total electromagnetic light power radiated on the cell. The conversion efficiency is highly dependent on solar irradiance [22] and solar cell temperature and efficiency differs for various solar cell technologies (mono- and polycrystalline silicon cells, thin-film CIS, CIGS, CdTe cells, amorphous silicon cells, dye-sensitized solar cells, etc.). For current market available silicon solar cells the conversion efficiency is in the range of 15–20%, however, module efficiencies are somewhat lower. The current maximum efficiency of optimally designed modern high efficiency silicon solar cells is about 25%. Intensive research in PV technology is characterized by slow but steady improvement in cell conversion efficiency. Presently, focus is paid on the research and development of new PV concepts such as high efficiency concentrated photovoltaics (CPV) and quantum-nanostructured PVs. CPVs already reach efficiencies of above 35% and the aim is to achieve 50% conversion efficiency.

PV module efficiencies of the most frequently used market available mono- or polycrystalline silicon solar PV panels (which make over 80% of the PV market) are in the range of 12–17% [24]. So, a simple calculation shows that to install 1 kW of PV power an area of about $6–8\,\mathrm{m^2}$ is required (the square shaped solar module array around $2.7\,\mathrm{m} \times 2.7\,\mathrm{m}$, for the module conversion efficiency of 15%; for Sanyo HIT-Si modules with PV system power $1025\,\mathrm{W_p}$ area size is $6.26\,\mathrm{m^2}$ what is $2.5\,\mathrm{m} \times 2.5\,\mathrm{m}$ [24]). A new concept in PV module manufacturing due to the move from the cells to modules will enable the further reduction of losses with achieving module efficiency beyond 35%.

To estimate PV system losses of solar PV grid-connected systems, a lot of factors have to be taken into account: temperature, angular reflectance, inverter losses, ohmic losses in cables, junctions and wires, partial shading effects, solar cells operating out of the STCs, possible dirt and snow on the PV modules, etc. All these conditions vary from season to season, from day to day, giving on average 10–30% less output power than the power actually produced by the PV module [25]. Inverter (DC/AC) losses are typically 5–10%, however this is expected to be substantially lowered [26]. For the most frequently used mono- or polycrystalline silicon solar PV panels and available inverter systems, losses are estimated to be between 20% and 25%. Thus, the performance ratio of the solar PV system is most often in the range of 0.75–0.8. For a performance ratio of the PV system at 0.75 and a PV module conversion efficiency of 15%, the required area for 1 kW of installed PV power is about $9\,\mathrm{m^2}$ (around $3.0\,\mathrm{m} \times 3.0\,\mathrm{m}$). It means that in real circumstances in Serbia, market available standard PV equipment assembled from fixed optimally inclined and oriented PV modules and mounted on area of about $9\,\mathrm{m^2}$ (installed PV power of 1 kW) harvests on average between 1150 kWh and 1200 kWh of electricity annually, while the daily average value is about 3.2 kWh of electricity.

The performance ratio of a PV system within PVGIS is calculated as the sum of estimated loss due to temperature (about 8.0%), estimated loss due to angular reflectance effects (in the range of 2.0–3.0%) and losses related to PV system installation (losses in junction boxes, inverters, cables, etc., about 14.0%). Overall, combined PV system losses within PVGIS are estimated to be between 24% and 25%.

The lifetime of PV modules depends on the solar cell technology used as well. For mono- and polycrystalline silicon solar cells, most manufacturers give a warranty of 10/90 and 25/80, which means: a 10-year warranty that the module will operate at above 90% of nominal power and up to 25 years above 80%. The practical lifetime of the silicon-made PV modules is expected to be at least 30 years. For the newer thin-film technologies, 10-year guarantees are customary, but experience with them is still limited. CPVs are still under intensive research and their duration properties are expected to be explored in their practical implementation in forthcoming years.

The energy payback time (EPBT) of PV modules is an important property of solar systems. EPBT is defined as the time the PV module has to operate in order to recover the energy consumed for its production (i.e. to recover the installation costs). EPBT differs for PV modules made by different technologies, it also depends on the total installed power of the PV system, and varies from country to country. In Germany for example, for PV systems assembled in mono- and polycrystalline cells and module technology, EPBT is estimated to be between 6 and 8 years, but for thin-film CdTe PV systems is estimated to be less than 3 years [3,27].

Grid-connected PV solar systems with optimally inclined and oriented PV modules and with 1 kW of installed PV power could yield, under Serbian circumstances, on average: $1550\,\mathrm{kW} \times 0.75 \times 23\,\mathrm{c€/kWh} \simeq 270\,€$ annually. For a guaranteed period of 12 years it is nearly 3300 €.

A two-axis sun-tracking PV solar system with installed 1 kW could yield, under Serbian circumstances, 30% to 35% more money, on average $\simeq 360\,€$ annually or for a guaranteed period of 12 years about 4300 €.

3.2. An example of a PV feasibility study for Serbia

Roughly speaking, there are four groups of parameters which have to be taken into consideration within a feasibility study on solar PV grid-connected systems. These are: solar irradiation parameters for a given location for a solar PV power plant; technical parameters of the planned solar PV modules and panels; the market prices of solar PV equipment and the cost of design, realization (mounting) and maintenance of a solar PV system; and the Government driven RES policy parameters. For Serbian circumstances, these parameters are presented in more detail in Table 3.

The authorities of any country, perhaps fortunately, cannot influence the first two groups of parameters (solar irradiation parameters and PV technical parameters). The authorities can affect some of the parameters included in the third group (PV market prices) by means such as customs taxes for RES equipment or land prices and taxes for RES power plant reserved terrain, however in general, those prices are market driven. In Serbian circumstances, customs tax for this type of technical RES equipment is below 3% of the purchase price, and land prices for non-agriculture terrains are very low at the moment.

Average (orientation) values given for the parameters in group 3 decrease with an increase in installed power of a PV power plant.

Table 3
Important parameters for a feasibility study on solar PV grid-connected systems in the Republic of Serbia.

No.	Group of parameters	Parameter	Average (orientation) value
1.	Solar irradiation parameters (annual averages for Serbia)	Horizontal plane solar irradiation	1350 kWh/m^2
		Vertical plane solar irradiation	1000 kWh/m^2
		Optimally inclined plane and orientation irradiation	1550 kWh/m^2
2.	Technical parameters of planned PV modules and panels	Solar PV cell efficiency	15% to 20%
		Solar PV modules and panel efficiency	12% to 17%
		Performance ratio of solar PV system	0.75 to 0.80
		The lifetime of PV modules	Over 25 years (silicon PV modules)
3.	Market prices of solar PV equipment, design, mounting and maintenance	PV modules and panels	3000 to 4000 €/kW
		Inverter	500 to 1000 €/kW
		Cables, junction boxes, and other PV equipment	Less than 100, on average 50 €/kW
		Custom, shipment and transport of PV equipment	100 to 200, on average 150 €/kW
		Land (occupied by PV power plant)	Less than 100, on average 50 €/kW
		Design (project) and mounting	200 to 400 €/kW
		Maintenance (insurance etc.)	Less than 100 €/kW per year
4.	Financial and the Government RES policy	VAT	18%
		Bank loan capital repayment annual rate	4% to 5% per year
		Feed-in tariff for solar PV produced electricity in Serbia	23 c€/kWh
		Guaranteed period for FIT	12 years
		Tax for produced electricity	0% (tax-free for guaranteed period)
		Energy payback time (EPBT)	To be calculated!

This is particularly the case with the purchase price of PV equipment and design (project) and mounting expenses.

The fourth group of parameters are greatly influenced by the Government RES policy. Bank loans and capital repayment rates for RES can be adjusted according to the Government policy to the RES energy sector. The Government can enable cheap loans, low repayment rates, tax relief, provide gratis periods in capital repayment procedures and create special incentives and subsidy programs for RES investments. Unfortunately, the Serbian Government is delaying in the creation of a good and attractive business environment in the RES sector, especially for solar PV grid-connected power plants, although some promising ideas and steps have been recently announced.

Grid-connected solar PV power engineering is undoubtedly the fastest growing power generation technology and industry at present. The latest JRC's PV status Report [4] reveals that in 2009, PV industry production increased by more than 50% and reached a worldwide production volume of 11.5 GW_p of PV modules. The Report highlights that in 2009, newly installed PV power-plants worldwide produced a peak amount of electricity estimated at 7.4 GW_p, out of which 5.8 GW_p was located in Europe. Business analysts predict that the PV market is soaring to reach a volume of € 40 billion in 2010.

Although over the last decade the solar PV industry has seen a huge increase in demand (for example, in 2008 worldwide solar module production increased 80% on the previous year, in 2009 a further 50% as a result of the global economic slowdown in 2009 and 2010). Market analysts found that the mean cost of installed PV dropped 3.6% annually from 1998 through 2008, with a decline of 4.6% from 2007 to 2008. Some PV prices have dropped more than 30% in the last two years, which is making it tough for manufacturers to survive. Under present conditions at the end of 2010 it seems likely that some PV prices are going to fall by another two digits percentage rate in 2011 and in 2012.

The PV market is poorly developed in Serbia where just a few PV sellers operate, but with unrealistically high prices for PV equipment and purchase conditions. Hence, to calculate investment costs for 1 kW of installed PV power a lot of European and US specialized Internet sites have been browsed and investigated (during the summer of 2010). The prices depend on the specific retailer, the PV cell and module technology used, the number of modules purchased, the retailer's country, etc. It is interesting to note that some of the US solar cell seller Internet sites are informing their customers that "*solar modules are in high demand in the European market which makes them difficult to obtain in the U.S.*". Many manufacturers and dealers charge 10–15% less for several modules purchased (e.g. more than 8 modules) with a further price reduction for larger purchases. The overall results show that the average purchase price for 1 kW of PV power is between € 3000 and € 3500 for various silicon solar PV panels and about € 500 for an inverter. To these basic PV expenses one has to add: shipment + custom taxes + VAT (18% in Serbia) + solar modules mounting and installation + land fees + . . .

Table 4 shows the calculated values for EPBT for a solar PV grid-connected power plant with installed power of 100 kW, under the conditions and average values of the parameters in Table 3 for four different locations in Serbia, in its northern (Novi Sad), central (Kragujevac), south-eastern (Leskovac) and south-western region (Novi Pazar), and for two type of PV systems: stationary or fixed (FIX) PV systems with optimally inclined and oriented module planes and two-axis sun-tracking PV systems (with rotators (ROT)).

Parameters from Table 3 are taken to be:

- Solar irradiation parameters for optimally inclined plane and orientation,
- Solar PV modules and panels efficiency – 15%;
- Performance ratio of solar PV system – 0.75;
- Price of PV module (panel) – 3000 €/kW (possible discount for several PV modules (panels) purchased);
- Price of inverter – 500 €/kW (possible discount for several devices);
- Other PV equipment – 50 €/kW;
- Custom tax (3%) + VAT (18%) – 500 €/kW;
- Shipment of PV equipment, land expenses – 50 €/kW;
- Design (project) and mounting – 200 €/kW;
- Bank loan capital repayment annual rate – (a) 4.0% per year, (b) 2.0% per year, (c) 0.0% per year;
- Maintenance – (a) 40 €/kW, (b) 20 €/kW, (c) 0.0 €/kW; and
- Feed-in tariff for solar PV produced electricity – 23 c€/kWh.

On the basis of the assumed parameters, the estimated investment price of a PV system in the Republic of Serbia is nearly 4400 €/kW. This is just an average estimation, because the solar cell technology used, the inverter technology and some other specific costs are not taken into account. More efficient state-of-the-art silicon or thin-film PV modules and more efficient inverters for

Table 4
Estimated parameters for a solar PV grid-connected power plant with installed power of 100 kW (would fit approximately 30 m × 30 m square shaped land) under practical conditions developed at four different locations in the Republic of Serbia. The last two rows give an estimation of investment price per 1 kW or estimation for FIT per 1 kW if one wants to drop down EPBT to a guaranteed period of 12 years. FIX: PV system with optimally inclined and oriented module planes; ROT: PV systems with two-axis sun-tracking PV system (PV system with rotators).

	Northern part of Serbia (Novi Sad)	Central part of Serbia (Kragujevac)	South-eastern part of Serbia (Leskovac)	South-western part of Serbia (Novi Pazar)
Total yearly solar irradiation in optimally inclined and orientated PV module plane	1473 kWh/m^2	1538 kWh/m^2	1529 kWh/m^2	1627 kWh/m^2
Solar electricity generated from installed 1 kW PV system (total annual value) for two types of PV systems	FIX: 1127 kWh (ROT: 1492 kWh)	FIX: 1177 kWh (ROT: 1582 kWh)	FIX: 1167 kWh (ROT: 1544 kWh)	FIX: 1255 kWh (ROT: 1654 kWh)
Solar electricity generated from 100 kW of installed PV system (total annual value) for two types of PV systems	FIX: 113 MWh (ROT: 150 MWh)	FIX: 118 MWh (ROT: 159 MWh)	FIX: 117 MWh (ROT: 155 MWh)	FIX: 126 MWh (ROT: 166 MWh)
Total annual production in € for 100 kW installed PV system	FIX: 26,000 € (ROT: 34,400 €)	FIX: 27,100 € (ROT: 36,400 €)	FIX: 26,900 € (ROT: 35,600 €)	FIX: 28,900 € (ROT: 38,100 €)
Estimated total investment price for 100 kW installed PV power plant; Only for fixed PV systems	440,000 €	440,000 €	440,000 €	440,000 €
Energy payback time EPBT for 3 cases:				
Case (a): 4.0% per year + maintenance expenses 40 €/kW;	41.0 years	36.5 years	37.3 years	31.2 years
Case (b): 2.0% per year + maintenance expenses 20 €/kW;	23.1 years	21.7 years	22.0 years	20.0 years
Case (c): 0.0% per year and without maintenance expenses; only for fixed PV systems	16.9 years	16.2 years	16.4 years	15.2 years
Estimated price of 100 kW investment for EPBT to be 12 guaranteed years;				
Case (a): 4.0% per year + maintenance expenses 40 €/kW;	207,000 €	217,000 €	215,000 €	234,000 €
Case (b): 2.0% per year + maintenance expenses 20 €/kW;	254,000 €	266,000 €	264,000 €	285,000 €
Case (c): 0.0% per year and without maintenance expenses; only for fixed PV systems	312,000 €	325,200 €	322,800 €	346,800 €
Estimated FIT for EPBT to be 12 guaranteed years;				
Case (a): 4.0% per year + maintenance expenses 40 €/kW;	45.0 c€/kWh	43.2 c€/kWh	43.5 c€/kWh	40.5 c€/kWh
Case (b): 2.0% per year + maintenance expenses 20 €/kW;	38.6 c€/kWh	37.0 c€/kWh	37.3 c€/kWh	34.7 c€/kWh
Case (c): 0.0% per year and without maintenance expenses; only for fixed PV systems	32.5 c€/kWh	31.1 c€/kWh	31.4 c€/kWh	29.2 c€/kWh

installed powers greater than 100 kW would certainly give an investment unit price of below 4000 €/kW.

In Germany, for instance [4], an average installation investment price for 1 kW of PV installed power has dropped down from 5000 €/kW in 2005 to even below 4000 €/kW in 2009. In Serbian circumstances the additional burdens are customs (3%) and VAT (18%) taxes. PV technology equipment is unfortunately not tax-exempted in Serbia. The author of this article has inquired about this VAT problem amongst several energy sector officials, customs services and VAT experts in Serbia, but has received quite discouraging answers, ranging from a huge lack of knowledge and general underestimation of PVs to certain claims that "PVs would never be tax-exempted in Serbia". This VAT and customs problem has to be urgently addressed by the Government of the Republic of Serbia concerning the whole RES and PVs power sector.

Results of calculations show that EPBT for solar PV engineering investments in the Republic of Serbia are estimated to be for case (a) over 30 years and for case (b) over 20 years. To enable EPBT to be 12 guaranteed years FIT for solar PV produced energy would be for case (a) over 40 c€/kWh and for case (b) over 35 c€/kWh. The inevitable conclusion is that the year 2011 seems not to be the best moment to invest in solar PV grid-connected power plant in Serbia. Realistically, the energy payback time is well above 12 (guaranteed) years, FIT level is very low, while a significant solar PV modules decline in pricing can be almost certainly expected in forthcoming years.

Furthermore, results show that the Serbian Government has made a mistake adopting the FIT for solar PV produced energy only at 23 c€/kWh. It can be seen that the FIT level at 35.4 c€/kWh proposed by Serbian energy sector experts group was much more realistic. The consequence of this Government mistake is still poor investment activity in the solar PV RES field in Serbia in spite of the wishes and desires of foreign and domestic investors.

As far as the author is informed from the Serbian media, there is only one serious investment plan to build a solar PV power-plant based on the sun-tracking rotator technology near city of Leskovac (location: Velika Biljanica), south-eastern Serbia. This investment is in its design phase and according to available data the development and mounting of this PV power-plant should start in spring 2011 and it is expected to be finished by the end of that year. The planned installed power is 950 kW and sun-tracking PV panels of approximately 20 m^2 area will be mounted on 330 rotating systems. If this 3.5 million € project is going to be realized during 2011 this would be possibly the first ever solar PV power-plant in the Republic of Serbia.

3.3. *Some lessons have to be learnt from Serbia's neighbours!*

Utilization of PV systems differs substantially from country to country due to different renewable energy policies, public support programs and specific levels of liberalisation of domestic electricity markets. In this subsection, a few descriptive examples are given from to the Republic of Serbia's neighbouring countries which can be recommended as lessons for the public and particularly for policy makers in Serbia. Most data is taken from the JRC PV Status Report published on the Internet in August 2010 [4]; other data sources and references are properly indicated.

3.3.1. *Lesson 1*

Greece has almost ideal sunny conditions with an average annual irradiation of near 2000 kWh/m^2 in its southern parts, for optimally inclined PVs. Greece failed to introduce adequate FITs for solar PV produced energy in the past which resulted in relatively poor solar PV utilization in practice [3,27] in comparison to other Mediterranean countries (such as Spain). FITs in Greece were relatively low for the PV produced electricity, so very few PV power plants have been installed. In the last few years, Greece has introduced substantially higher FITs and they are at the moment at a level from 40 to 50 c€/kWh [27]; rooftop PV systems up to 10 kW$_p$ receive 55 c€/kWh. FITs are guaranteed for 20 years and Greece has

the highest FITs for purchasing the PV produced electricity in the region. Greek authorities have drastically cut administrative procedures, for example small PV system installations, with installed power of less than 20 kW, do not need any licence at all! For PV systems from 20 to 150 kW only environmental impact assessments are needed [27].

3.3.2. Lesson 2

Bulgaria has similar sunny conditions to Serbia (more favourable in its Black Sea region), but pays 40.5 c€/kWh for PV systems up to 5 kW and 37.2 c€/kWh for PV systems >5 kW and ≤10 MW and solar PV power engineering is flourishing in this neighbouring country. PV system projects are financed with reduced interest loans from the Bulgarian Government, the European Bank for Reconstruction and Development (EBRD), the Bulgarian Government and the EU. In November 2008 the duration of FIT payments for PV systems was changed from 12 to 25 years. As an additional example of good RES policy, Bulgaria's wind energy capacity jumped over 300 MW by the end of 2009.

3.3.3. Lesson 3

The Former Yugoslav Republic of Macedonia (FYR Macedonia) has better sunny conditions than Serbia with as many as 280 sunny days a year. The first grid-connected solar PV power plant started to work in July 2010, near its capital Skopje, with installed power of 250 kW, and an investment price of about 1 million € [28]. Unfortunately, the Government of FYR Macedonia in July 2010 lowered the FITs for solar PV produced electricity for the third time in one year – from 46 c€/kWh down to 30 c€/kWh (for systems of up to 50 kW) and 26 c€/kWh (for systems from 50 kW up to 1000 kW) [29] with the guarantee of purchasing electricity for the next 15 years. This weird management by the FYR Macedonia Government has pushed many foreign investors, amongst which is the German company HB Solar, to think about leaving their investments in Macedonia. The overly high administrative barriers and the frequent modifications of the regulatory policy for PV business are not attractive for serious companies.

3.3.4. Lesson 4

The Czech Republic is a northern country in comparison to Serbia with an average annual irradiation level of 1170 kWh/m^2 for optimally inclined PVs, which is nearly 30% worse than in Serbia. However, the Check Republic has made a lot of investments in micro and mini solar PV power plants in recent years with great success, becoming a leader in the solar PV engineering field in the Central Europe. The FITs in the Czech Republic are from 43 to 48 c€/kWh with a guaranteed period of 20 years and investors are offered generous subsidies, income taxes exemptions and VAT reductions. The Czech PV capacity reached 200 MW at the beginning of 2010 (from only 3 MW in 2007).

3.3.5. Lesson 5

Spain and Germany can serve undeniably as the best examples of how to approach successfully the implementation process of solar grid-connected PV systems. For instance, the newly updated Spain tariff scheme established in 2007 [30] regulates the production of solar PV electricity in the following way: for PV power plants with installed power less than 100 kW, the first 25 years' guaranteed FIT is 44.0381 c€/kWh and after that 25 years the guaranteed FIT is 35.2305 c€/kWh; for PV power plants with installed power greater than 100 kW and less than 10 MW, the first 25 years guaranteed FIT is 41.7500 c€/kWh and after that 25 years the guaranteed FIT is 33.4000 c€/kWh, etc. Analyses show [27] that although FITs are an important condition for growing PV utilization, they can only give results if PV policy support is stable and consistent and policy risks are carefully managed.

4. The importance of information dissemination about PVs

Solar energy as a source of renewable energy has vast potential and it is the challenge facing the world's energy future. Grid-connected solar PV produced electricity is expensive at the moment, but this is just a transitory situation, one has to be educated, trained and prepared for the future almost certain scenario of the favourable use and exploitation of PV electricity generation.

It is a well known fact that there is constant opposition attempting to give false or negative information about solar PV technology. The Serbian public is not immune to this. False information is mainly about PV cell and module costs (too high or too low), their detrimental effects on the environment, there is an underestimation of PVs in comparison with other RES technologies, etc. It is pretty easy to find proven information about PV solar cells and systems in scientific and technical journals, on the Internet sites providing specific information about producers of PV technology, prices of PV equipment, do-it-yourself (DIY) guides, etc. Nevertheless, the field of PVs seems to be treated by the Serbian public in some kind of mystic sense. The main reasons why PV technology is not appreciated in Serbian professional and public domains are: a lack of proper knowledge and understanding of PV potentials and an energy policy regulating the RES and PV energy sector that is still inefficient and inconsistent.

There are very few available articles in Serbian technical literature and research reports which deal with the assessment and evaluation of solar PV utilization in Serbia [31,32]. If one can find some of them, these are usually about stand-alone solar PV systems, hybrid alternative power supply stand-alone systems [33,34] or reviews about simple solar thermal and small solar PV roof maintained units. In references [14,35] only assessments for solar thermal energy systems and for small housing solar PV units installations are considered for mainly stand-alone solar PV systems, with concluding remarks that the use of solar energy is currently almost negligible. There is a feeling that the authors of these articles were not fully aware about the electricity production from solar PV power-plants which, besides stand-alone systems, can be configured as grid-connected systems as well.

Poorly informed and educated public and even professionals and policy makers represent huge obstacles in the Republic of Serbia for introducing PV solar power-plants in its energy sector. Some of the dominant arguments by the Serbian public (even literature) against PVs are quite uncertain: "the PV equipment is very expensive" (without any estimation and calculation having been made), "PVs are unfavourable RES possibility because the PV equipment has to be purchased as foreign equipment" (neglecting the fact that more than 95% of vehicles on Serbian roads and almost 100% of TV units and mobile phones in Serbian homes are of foreign origin).

It was mentioned in Section 1 that the Serbian Government recently drastically dropped the FIT of 35.4 c€/kWh proposed by the energy sector experts group down to 23 c€/kWh for PV produced electricity, therefore placing Serbia at the bottom of the list of countries that have introduced FITs in the region. It has been explained that the Government is afraid of enabling budgeting for high FITs, but it seems that real threat and purpose was to enable competitiveness in the energy sector and to disable the possibility of companies and individual making a profit from PV electricity producing. However, a preferential FIT for PVs is never costly if a target is to enlarge the PV industry and energy sector. Further VAT, customs and other taxes have to be removed, or at least significantly cut for case importing RES and PV equipment. PV electricity production must be a profitable business and activity otherwise no one would invest their time and money in it. A lack of knowledge, administrative delays and bad steps of policy makers might be much more costly for everyone in the future.

Another incorrect estimation, which is perhaps rewritten from article to article, is that the share of solar energy in the total Serbian RES sector is only potentially 10–15% (a graph chart at the SMME web-site http://www.mre.gov.rs/ shows 14%). Authors of papers analysing solar energy utilization in Serbia usually pick a number around 15%, give or take one or two percent, presumably calculating total available building rooftop and facades area in Serbian urban regions, or potentials of rooftop solar thermal utilization only. This could be disseminated easily with the following futuristic example. If a PV module (or panel) area of about 3 m × 3 m, assembled in the present market available silicon PV technology with a conversion efficiency of 15%, gives installed power of 1 kW, then 3 km × 3 km PV settled area would give the installed power of 1 GW, which is on average 1200 GWh of the PV electricity produced in Serbia annually. In the official Report of the SMME [17] it is stated that the production of the electricity in Serbia in 2008 is estimated to be 36,827 GWh (25,933 GWh in fossil fuel power-plants and 10,330 GWh in hydro-power-plants). Therefore, about 30 PV power-plant square shaped units 3 km × 3 km might replace the total yearly Serbian electricity production. Or, the electricity production of just a single 16.5 km × 16.5 km square shaped PV power-plant would be equal to the production off all hydro-, thermo- and all other power-plants in Serbia. One can compare this 16.5 km × 16.5 km square shaped (environmentally almost completely friendly) area to the total area drowned so far by the accumulation of lakes needed for proper operation of large hydro-power-plants, and the additional harmful sociological, environmental, CO_2 polluting, agricultural, micro-climatic and economic impacts of existing traditional large-scale, mainly high-polluting coal-fuelled, power plants in Serbia.

Hence, it is not only 14% of RES potential, it could be 100% of all traditional plus other RES potentials all together! It is true that the investment cost for 3 km × 3 km PV power-plant would exceed 3 billion € in 2010, however, if the Republic of Serbia invested 1 billion € in research (people + labs) and the domestic manufacturing of PV technology, for the remaining 2 billion €, Serbia would have not only one 3 km × 3 km PV power-plant but several of them! Unfortunately, the solar produced electricity in not evenly distributed during the day and year, the PV produced electricity has to be stored during the day (or summer) for night (or winter) use, and the aforementioned futuristic scenario is not an easy task to be realized. However, this example can serve as a breaking fact in the wrong understanding of the potential of solar PV produced electricity in the Republic of Serbia. Finally, in reference [36] an original and an impressive scenario of resolving the future global world's energy needs with solar PV capacities is given.

Another failure is to acquire information about highly cheap PV equipment "made in China". The public, even professionals in the Serbian energy sector, are spreading information about extremely cheap offers from Chinese companies for their PV products, however, no one can give accurate details about the solar cell technology of those PV modules and about their technical parameters. The truth is that the People's Republic of China has become the leading world country in the PV industry. In 2010, Chinese PV manufacturers succeeded in reducing the production cost of solar PV cells from about 4.4 €/W_p in 2000 to about 1.2–1.6 €/W_p [4], however commercialised PV modules have an efficiency of 10–13%, which in overall gives cheaper but not hugely cheaper PV equipment.

The aforementioned examples illustrate the very poor overall informational and educational level in the field of PV technology and utilization in the Republic of Serbia. A decade or two ago some other developed European countries were faced with the same problem. Investments in education and information dissemination about PVs are usually the best way to overcome this problem and to improve the public and professional awareness of the potential PV contribution in the future global energy and economic structures. A broad educational action about RES and especially PVs has to be launched in Serbia if Serbia wants to acquire this very attractive and highly promising RES possibility.

5. Conclusion

Insufficient awareness of the opportunities of solar PV produced electricity may be an obstacle which can significantly limit and delay its use in the Republic of Serbia. Therefore, the main objective of this paper is to assess in more detail the potential for solar PVs utilization and the current situation in solar PV engineering in Serbia and to encourage the Serbian authorities, professionals and public to improve their awareness and activities in the solar PV energy sector. At the moment solar PV technology is not implemented in the Serbian RES sector and initiatives to take some firm steps in this direction are expected. Serbian authorities have recently acquired policy framework in the RES sector and FIT incentives have been introduced as the best way in promoting and developing new emerging and clean RES technologies. It is important to highlight that FITs incentives policy, particularly for solar PV produced electricity, has to be the subject of a steady improvement process in the forthcoming years if true results are expected in the future. The Serbian Government has to be more subtle in its activities and learn lessons that have been recently taught in neighbouring countries in the field of introducing and developing of solar PV technology. The goal of successful implementation of solar PV systems in Serbia could be achieved primarily with steady as you go positive Government policy in the RES energy sector, broad and systematic education of customer and engineers in the new emerging solar PV technology and extensive further support in this field.

In this article, the potentials for solar PVs utilization in Serbia are estimated and assessed in more detail. PVGIS based maps for average annual solar irradiation for the territory of Serbia are presented and analysed. An example of a feasibility study for a PV grid-connected power plant in Serbia is given. The calculations performed within this study can serve as a helpful guide for initial practical activities in the Serbian PV power engineering field. The importance of the educational issue and information dissemination in RES and particularly PVs in Serbia is emphasised. The author believes that the assessments, examples, calculated data and suggestions presented in this article can be helpful not only to everyone who wants to participate in developing and investing in solar PV technology in Serbia, but they can also be helpful to the Serbian Government to improve its regulatory legislation in the RES sector and to make an efficient policy which can enable competitive investment and utilization of solar PV systems in Serbia.

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